

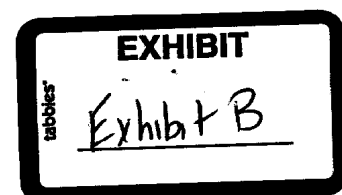
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CATERPILLAR®

Truck Application and Installation Guide

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Caterpillar Truck Engines Application & Installation Guide

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INTRODUCTION

This booklet is a basic reference and guide for the correct application and installation of Caterpillar Engines in trucks and buses. Its primary purpose is to assist engineers and designers specializing in engine selection, application and installation. *The Truck Engine Installation Drawings, Truck Electronic Application and Installation Guide, and Truck Engine Performance* booklets complement this booklet.

ENGINE INSTALLATION AND TECHNICAL REVIEW

Caterpillar Engines are designed and built to provide superior value; however, achieving the end user's value expectations depends greatly on the performance of the entire power train consisting of various components and systems, of which the engine is only one part, albeit a vital part.

In order to validate the engine performance and better assure end user satisfaction, Caterpillar requires a *mandatory* technical review of OEM customers' initial engine installation as a *prerequisite* to the sale of engines on an outgoing basis. Additionally, a review is necessary whenever a change is made to the installation which might affect the engine's overall performance. It is the OEM's responsibility to inform Caterpillar when such changes are made.

This review is performed by the OEMs personnel at their facilities with qualified

Caterpillar technical personnel assisting on a free-of-charge basis. Particular attention is given to cooling, air intake and exhaust, fuel, electronic and electrical systems, mounting and mechanical drives, serviceability, and operator safety. A copy of Caterpillar's installation review report is provided to the OEM. The review report documents the important features and details of the engine installation and indicates those characteristics judged satisfactory, unsatisfactory, and likely to lead to user dissatisfaction, or marginally satisfactory, depending on the extremes of the operating environment. The review report will recommend improvements to the installation as appropriate.

Although Caterpillar exercises all reasonable effort to assure engines perform properly in the OEMs equipment, the responsibility for the engine installation is the OEMs, and Caterpillar assumes no responsibility for deficiencies in the installation.

It is the installer's responsibility to consider and avoid possibly hazardous conditions which could develop from the systems involved in the specific engine installation. The suggestions provided in this guide regarding avoidance of hazardous conditions apply to all applications and are necessarily of a general nature since only the installer is familiar with the details of his installation. The suggestions provided in this guide should be considered general examples only and are in no way intended to cover every possible hazard in every installation.

Trucks, Engines, and Applications

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TYPES OF ENGINES AND TRUCKS

Caterpillar Truck Engines are designed to meet the specific performance requirements of two general, but distinct types of truck applications. Depending on the *severity of the application*, they are *medium-duty* or *heavy-duty* engines.

Other terms, many descriptive of the application or chassis, and regional in nature, are used to indicate the type of truck. To avoid the limitations and inconsistency of terms, only medium and heavy-duty terminology is used in this manual.

APPLICATION SEVERITY

Truck engines and trucks are designed for the severity of an application. Severity refers to how hard the engine and truck must work to get the job done or the performance demanded by the application. Severity can easily be determined by identifying eight application factors.

Application Factors or Conditions

Factors Determining Application Severity:

- Average fuel consumption (% load factor)
- Engine operation per shift
- Average travel speed
- Type of operation
- Miles traveled per shift
- Annual mileage
- Gross vehicle weight
- Ratio of average GVW to maximum GVW

Load Factor

(Average Fuel Consumption)

Average fuel consumption is a means of determining the average horsepower produced by the engine. To make average fuel consumption and horsepower meaningful in terms of how hard the engine is working, both are stated as *load factor*. Load factor is calculated with this formula:

$$\frac{\text{average fuel rate (gal/hr)}}{\text{maximum fuel rate (gal/hr)}} \times 100 = \text{Load Factor (in \%)}$$

To illustrate the load factor formula, assume an engine is rated 210 hp. Dynamometer tests of specific fuel consumption show it will consume a maximum of 12 U.S. gallons of fuel per hour when operated continuously at 210 hp. This is the *maximum fuel rate*.

The *average fuel rate* is the volume of the fuel consumed during a typical cycle of the application. This requires accurate measurement of fuel consumption for a complete operating cycle, including no load as well as maximum load.

Continuing the example, the average fuel rate of the 210 hp engine is measured at 4 gallons per hour. The calculations look like this:

$$\frac{\text{average fuel rate}}{\text{maximum fuel rate}} \times 100 = \frac{4 \text{ gal/hr}}{12 \text{ gal/hr}} \times 100 = 33\% \text{ Load Factor}$$

From this, the average horsepower developed is calculated by multiplying the 210 rated hp by the 33% load factor for 70 hp.

This example indicates a light application. If the average fuel rate had been 10 gallons of fuel per hour, load factor would be 83% with an average of 174 hp, constituting a severe application.

Engine Operation per Shift (8-10 Hours)

Heavy-duty vehicles often operate 80-100% of an 8-10 hour shift. Because medium-duty vehicles may make frequent stops or are required to wait long periods to load or unload, the actual operating time per shift will be 50-90%.

Modern fuel saving techniques dictate the engine be shut off if the idle time per stop is in excess of 5 minutes. Exceptions to the rule are for driver comfort in cold or warm climates, in construction work where the vehicles are called on to move a short distance frequently, or if power takeoff operation is required with the vehicle at rest.

Average Travel Speed

Average travel speed is calculated by the following equation.

$$\frac{\text{Miles Traveled per Shift}}{\text{Travel Time in Hours}} = \text{Average Travel Speed}$$

Do not include idle time and engine shutoff time in travel time.

High average travel speed indicates few stops were made and a high cruising speed. Together these can result in high horsepower demands and high load factors.

Type of Operation

The following are examples of types of operation ordered from light medium-duty to severe heavy-duty conditions.

- a. Central city pickup and delivery.
- b. Suburban (intra-city) pickup and delivery.
- c. Two-lane highway under 55 mph speed limit (88 km/h).
- d. Two-lane highway 55 mph speed limit (88 km/h).
- e. Freeway or Interstate under 55 mph speed limit (88 km/h).
- f. Freeway or Interstate 55 mph or over speed limit (88 km/h).

Examples *a* and *b* are strictly stop-and-go service with low average travel speeds and low percent engine operation per shift. Gearing frequently is low for good acceleration and payloads vary due to deliveries and pickups. Often, the truck travels empty.

Examples *c* and *d* have higher horsepower demands and load factors. The trucks are probably geared for higher speeds with minimal stops, resulting in higher average travel speeds. Unless there are offsetting factors, such as low GVW or frequent stops, these applications could be heavy-duty.

Examples *e* and *f* are typical of heavy-duty applications and must be carefully examined to determine whether the high speed horsepower demands are sufficiently offset by low GVW, low percent engine operation per shift, or other conditions making the application suitable for a medium-duty engine.

Miles Traveled per Shift (8-10 Hours)

Shift mileage is a good check on other aspects of an application. High cruising speeds, for example, and low mileage per shift seldom occur together.

Annual Mileage

High annual mileage (above 70,000 miles) is typical of heavy-duty trucks. They travel at uninterrupted high speeds between cities. There are exceptions, usually heavy-duty construction trucks, such as dump or transit mixer trucks.

Medium-duty truck annual mileage generally is 12,000-60,000 miles (19,000-97,000 km). This is due to low average speeds and stop-and-go operations; however, engine hours of operation are substantial. Medium-duty trucks have lower mileage life compared to heavy-duty trucks. High daily mileage could cause unacceptably short overhaul periods even though performance and economy otherwise are excellent.

Gross Weight

Gross weight must be limited in medium-duty applications to keep load or horsepower demand on the engine at an acceptable level. Depending on the type of truck, van, trailer, dump or transit mixer, the normal permissible gross weight ranges from 20,000 lbs. to legal limits. The permissible gross weight is inversely proportional to maximum travel speed. The higher the speed, the lower the permissible gross weight, and vice versa.

There is no application restriction on the gross weight of medium-duty or heavy-duty engines other than legal weight. Minimum horsepower, to ensure the engine has enough horsepower to move the load at the desired speed, is sometimes a consideration.

Average Gross Weight Load Factor

Average gross weight load factor is calculated by the following equation.

$$\text{Load Factor} = \frac{\text{Empty Truck Weight} + \text{Average Payload} \times 100}{\text{Empty Truck Weight} + \text{Maximum Payload}}$$

The load factor is the percent of time a truck operates partially loaded. Medium-duty trucks make deliveries or pick up loads enroute and seldom operate at full load. Many travel empty one way. Heavy-duty trucks are usually loaded all of the time. Tankers and construction trucks are exceptions.

A balance of performance and economy coupled with vehicle initial investment, trade cycle, and residual value influence selection of the appropriate engine rating. Consult individual engine specification sheets or catalogs for specific rating recommendations or limits.

Engine Selection

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GENERAL PROCEDURE

After identifying the application as instructed in Section A, determining the horsepower required will help in selecting the correct engine. The horsepower required by the application selection alone can dictate a heavy-duty engine. If it exceeds medium-duty engine ratings, a heavy-duty engine must be used. If the required horsepower falls within the medium-duty range, the application must be taken into account. First, verify that the rating being used is neither too large nor small for the application.

HORSEPOWER REQUIREMENTS

Selecting an engine with enough, but not too much, horsepower to provide the performance specified by the customer involves looking at the entire powertrain. For brevity in the section, it is assumed that powertrain factors other than those affecting horsepower have been correctly matched to the engine.

MEASURING TRUCK PERFORMANCE

Regardless of how the horsepower for an application is determined, the determination must be made in terms of the following four measures of truck performance.

Maximum Road Speed (mph)

This is the maximum attainable road speed for the conditions under which the truck will operate.

Road speed is often improperly assessed. A top speed may be demanded that is illegal or economically impractical from an application standpoint. If a certain speed cannot be produced from a powertrain, the engine is usually blamed for *lack of power*. When other factors such as less startability due to higher gear speed or wind resistance, the following factors must be considered in making this measure.

Load may be the cause. The heavier the vehicle the less speed attainable for the same set of conditions and net engine horsepower.

Road Conditions: These are not as important for on-highway applications. Most vehicles operate on first class highways or Interstates. For those trucks operating both on-off highway, or completely off-highway, road conditions are a very important consideration.

Wind: A small increase over an already high speed greatly increases the horsepower needed to overcome wind resistance. Vertical side ribs on the body or van have higher wind resistance than do horizontal and smooth sided vans. An open load such as a car carrier can have from 50 to 100% more wind resistance than an enclosed van. Prevailing winds are usually considered insignificant, but their effect is the same as increasing the road speed. More horsepower is needed and travel speeds can be decreased by head winds.

Altitude: Operating in higher altitudes can reduce performance because it limits air intake by the engine. Naturally aspirated engines lose about 3% of their gross horsepower for each 1000 feet rise above sea level. Caterpillar turbocharged engines can go higher in altitude before derating becomes necessary. For specific derations of Caterpillar Engines, check the *Truck Engine Data Sheet*.

Cruising Road Speed (mph)

This is the speed (rpm) an engine is operating at while achieving good fuel economy. For Caterpillar Truck Engines, this rpm is between 10 to 20% below rated or governed rpm. In certain very fuel efficient specifications, this rpm could be as low as 40% of rated rpm. The *balanced performance* powertrain allows the engine to operate at least 10% below rated speed in direct drive or overdrive with the truck traveling at the desired or legal speed limit. Maximum road speed is reserved for passing and gaining momentum for climbing hills. Cruising speed horsepower requirements must be calculated while considering the factors affecting maximum road speed horsepower.

Gradeability (percent)

This is the maximum grade the truck can negotiate at a given speed.

Gradeability is easy to measure in a vehicle but difficult to select and apply. Under a given set of conditions one can easily determine just how steep a grade a vehicle can negotiate. It is of more interest, however, to know just how fast a truck can climb grades encountered over a specific route. This is important to the owner due to the effect of grades on trip times.

Wind, depending upon the speed a grade is negotiated, can be a significant factor when considering gradeability.

Startability (percent)

This is the ability to start the load moving from a dead stop, based on the most severe conditions under which the truck will operate.

Startability of a truck is directly related to its total gearing ratios. Good startability and proper speed ratios don't just happen, they are the result of planning.

Startability is affected greatly by conditions of load and grade. As the load becomes heavier and the grade steeper, the problem is magnified proportionally. Gradeability calculations are based on maximum torque while startability is a function of torque available in the low speed range of 800-1000 rpm. The minimum grade startability in first gear should be approximately 10% for general purpose linehaul vehicles and considerably greater for vehicles in on/off-highway service (15% minimum). Some applications may be adequate with a grade startability between 6% to 10% but should be reviewed. The absolute minimum for any vehicle should be 6%.

CALCULATING HORSEPOWER REQUIREMENTS

A variety of means is available for calculating gross and net horsepower demand. When none of these are available, use the following formula to check horsepower requirements at any speed and grade. The horsepower required is the sum of the following components:

- Total drivetrain loss.
- Air resistance.
- Rolling resistance.
- Grade resistance.

Horsepower required at the flywheel equals the sum of the following:

Drive Train Losses =

$$(1 - \text{Driveline Efficiency}) \times (hp_A + hp_{RR} + hp_G)$$

hp_A = Air Resistance Horsepower

hp_{RR} = Rolling Resistance Horsepower

hp_G = Grade Resistance Horsepower

There is a 3-5% loss in horsepower through every component of the drive train. Thus, if the vehicle has a main transmission, auxiliary transmission, and a single rear axle, the driveline efficiency is 0.88 ($0.96 \times 0.96 \times 0.96$).

Air Resistance Horsepower =

$$\frac{\text{mph}^3}{375} \times 0.00172 \times \text{Frontal Area} \times \text{Modifier}$$

mph = miles per hour

Frontal Area =

Width in ft x (height in ft minus 0.75 ft)

Modifier: If an aerodynamic improvement device or system is used on a typical freight van, the modifier is 0.60. If no device is used, the modifier is 1.0. As truck aerodynamics improve, the modifier may decrease to less than 0.60.

Rolling Resistance Horsepower =

$$\frac{\text{COR} \times \text{GVW or GCW} \times \text{mph}}{750,000}$$

COR = Coefficient of rolling resistance in pounds horizontal force/ton of vehicle weight. For Example: On good concrete, bias ply tires have a rolling resistance of 17 lb/ton and radial tires 11 lb/ton. Low profile tires can result in even lower rolling resistance.

GVW or GCW = Gross weight of the vehicle in pounds.

Grade Resistance Horsepower =

$$\frac{\text{Grade} \times \text{GVW or GCW} \times \text{mph}}{37,500}$$

Grade = Slope of road expressed as a percent.

ENGINE SELECTION AND POWER TRAIN CHECKLIST

Gross Horsepower

Gross or rated horsepower is adequate for accessory load and required net flywheel horsepower requirements at maximum road speed under normal conditions.

Net Horsepower

Net flywheel horsepower is adequate at cruising speed under normal operating conditions. To check this, determine the horsepower available at approximately 10 to 20% below rated speed from the engine performance curves.

Transmission Speed Ranges

Transmission has sufficient speed ranges so that the engine rpm does not fall below peak torque rpm when shifting to the next higher range at speeds above 30 mph. At road speeds below 30 mph, the demand horsepower is usually so low that engine operation below peak rpm is acceptable.

Startability and Gradeability

Startability and gradeability meet or exceed minimum requirement.

Proper Engine Application

Engine is proper for the application, heavy-duty or medium-duty.

ENGINE RATINGS

Performance curves for Caterpillar Truck Engines are contained in the *Truck Engine Performance* book. Similar performance curves appear on the specification sheets for each model.

All Caterpillar Truck Engines are rated under these conditions.

Without fan unless specified otherwise on the performance curve.

Standard SAE J1995 conditions of 29.3 in. (99 kPa) Hg and 77°F (25°C).

Fuel oil having a gross heat value of 18,390 Btu per pound (42,780 kJ/kg), weight of 7.001 lb/U.S. gal (838.9 g/L).

Standard engine equipped with fuel, lubricating, water pumps, and air compressor. Both heavy-duty engines and medium-duty engines are rated without air cleaner, fan and alternator.

Gross flywheel horsepower under the above conditions are within a nominal tolerance of $\pm 3\%$.

TRUCK PERFORMANCE COMPUTER PROGRAM

Caterpillar offers personal computer based software, *Cat Truck Engine Pro* for establishing the expected performance of a selected powertrain.

MARKET AREA

Due primarily to the availability of different types of oil in the world the following chart shows where various configurations of the 3116/3126 engine should be marketed.

3116/3126 Truck Engine Market Area (1)

Engine	Regulated Markets						(3) Russia & CIS CD Oil or Poorer
	U.S. Canada Australia New Zealand	Mexico	South America (Requiring Euro Cert)	Africa, Middle East and Far East	Europe	Markets with CF4/ CG4 Oil	
3116 MUI • EURO II Certified • 2 MICR Fuel Filter • Loose Top Land Piston	N/A	N/A	Y	Y	Y	Y	Y
3116 HEUI/3126 • EURO II Certified (5) • 2 MICR Fuel Filter • Tight Top Land Piston	N/A	N/A	Y	Y	Y	Y	N
3116 HEUI/3126B • EPA Certified • 2 MICR Fuel Filter • Tight Top Land Piston	Y	(2)	N/A	(2)	N/A	(2)	N/A
Truck Requirements Primary Fuel Filter (4) Water Separator	Req'd Recom.	Req'd Req'd	Req'd Req'd	Req'd Req'd	Req'd Recom.	Req'd Req'd	Req'd Req'd

Notes

- 1) CF4/CG4 multiviscosity oil required for all engines as stated in the operation and maintenance manual.
- 2) Do not sell unless CF4/CG4 multiviscosity availability is assured.
- 3) 3,000 mile oil change period and additional oil sump capacity is required when using typical Russian oil. 28L required for 200 HP and below, 39L required for 250 HP. For other ratings contact the 3116/3126 product group.
- 4) Primary fuel filter specification; 200 gram minimum sediment capacity (SAE J905) with 150 or less micron rating. When applied in locations where particularly dirty fuel is expected to be encountered, consult the factory.
- 5) The total rotating inertia of the transmission and accessories must be verified by the OEM to be within the certified range. Euro certification is not available for direct drive fans.

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GENERAL

This chapter is designed to answer basic questions about initial start-up in the factory to operating techniques on the road. It supplements the operating instructions and troubleshooting guides and performance check lists in the Caterpillar Truck Engine *Operation and Maintenance Management and Service Manuals*. If more data of this type is needed, it can be found in these publications. They can be ordered from your local authorized Caterpillar Dealer.

INITIAL START-UP CHECKLIST

Before starting an engine for the first time, check these items in *sequence*.

Be sure the first three are checked by the person actuating the starter switch. It's the only way to avoid finding out too late that someone overlooked the following critical points.

Before Starting the Engine:

General Inspection

Visually check entire installation. Carefully check for loose oil and water lines, fittings and loose belts.

Engine Coolant Level

If radiator was filled sometime before start-up, recheck in case the radiator was only partially filled. Caterpillar Engines will fill, but the radiator and piping added to the system may have a tendency to give a false fill. It, therefore, is recommended that the radiator always be checked after the initial fill (and every fill thereafter) to make sure the radiator and engine are full of coolant.

Crankcase Oil Level

Check both sides of the dipstick, as some have markings on both sides. One side is for checking the level with the engine stopped; the other side is for checking the level when the engine is running. If the marking is for checking oil level when running, the oil level

will be above the full mark when the engine is stopped. Refer to the *Truck Engine Data Sheet* for the correct type, grade and weight of oil.

Depress Clutch

Depress the clutch to remove transmission load from the starter motor.

After Starting Engine:

General Inspection

After the engine has been started, check the following points while the engine idles and warms up.

Engine Oil Pressure

Stop engine immediately if no pressure is indicated and determine cause before restarting. See *Truck Engine Data Sheet* for minimum oil pressures.

Engine Coolant Level

Check coolant level. Refill to proper level if low. (Be sure to first release cooling system pressure.)

Leaks

Check for oil and water leaks.

Unusual Sounds

Listen for abnormal sounds or unusual noise.

Accelerate Engine Slowly

Slowly accelerate engine to high idle. Continue to check for leaks, vibration, excessive noise, etc. Check throttle linkage for proper adjustment. Broken link must deflect at the high idle position on mechanically governed engines.

Acceptance Test

Make needed adjustments and run your required acceptance tests. If dynamometer testing is required, thoroughly warm up the engine by running at part load and speed for about 15 minutes. Observe coolant temperature while under load.

GENERAL OPERATING PROCEDURES

Comprehensive operating instructions are contained in the *Operation and Maintenance Management* Manual provided with every engine. After reading the instructions, owners often ask, "Is this really important?" The most frequent questions of this type are answered below.

Break-in Period

Every Caterpillar engine must pass a full load operation test on a dynamometer before shipment, eliminating the need for a break-in period. Only an initial operational check is necessary. Its purpose is to insure the engine has been assembled properly, determining if proper pressures and temperatures are maintained, correct any leaks, and perform necessary adjustments, such as throttle linkage.

Continuous at Rated Speed

Will operating continuously at rated speed damage the engine? This question is a result of the recommendation to operate (cruise)

approximately 20% to 40% below rated speed, for maximum fuel economy. Caterpillar engines can operate continuously at full rated speed. Lower fuel economy (higher fuel consumption) is the penalty.

Lugging the Engine

Caterpillar truck engines have good lugging characteristics with maximum torque occurring at 50-70% of rated speed.

Turbocharged engines can be lugged down to peak torque before down shifting. Running continuously at peak torque rpm at full load will not damage turbocharged Caterpillar engines.

Disassembly and Assembly

During the course of an installation, some external bolt and part probably will be adjusted, loosened, or removed. The question then is how tight should the bolt(s) be. On Caterpillar engines this problem is simplified by using only Grade 8 bolts. Tighten Caterpillar supplied bolts to the values given in Figure 1.

Metric Nuts and Bolts		
Thread Size	Standard Torque	
	N•m	lb ft
M6	12 ± 3	9 ± 2
M8	28 ± 7	20 ± 5
M10	55 ± 10	40 ± 7
M12	100 ± 20	75 ± 15
M14	160 ± 30	120 ± 22
M16	240 ± 40	175 ± 30
M20	460 ± 60	340 ± 45
M24	800 ± 100	600 ± 75
M30	1600 ± 200	1200 ± 150
M36	2700 ± 300	2000 ± 225

Metric Taperlock Studs		
Thread Size	Standard Torque	
	N•m	lb ft
M6	8 ± 3	6 ± 2
M8	17 ± 5	13 ± 4
M10	35 ± 5	26 ± 4
M12	65 ± 10	48 ± 7
M16	110 ± 20	80 ± 15
M20	170 ± 30	125 ± 22
M24	400 ± 60	300 ± 45
M30	750 ± 80	550 ± 60
M36	1200 ± 150	890 ± 110

Figure 1

Figure 1 (continued)

Inch Nuts and Bolts		
Thread Size	Standard Torque	
	N•m	lb ft
1/4	12 ± 3	9 ± 2
5/16	25 ± 6	18 ± 4.5
3/8	47 ± 9	35 ± 7
7/16	70 ± 15	50 ± 11
1/2	105 ± 20	75 ± 15
9/16	160 ± 30	120 ± 20
5/8	215 ± 40	160 ± 30
3/4	370 ± 50	275 ± 35
7/8	620 ± 80	460 ± 60
1	900 ± 100	660 ± 75
1 1/8	1300 ± 150	950 ± 100
1 1/4	1800 ± 200	1325 ± 150
1 3/8	2400 ± 300	1800 ± 225
1 1/2	3100 ± 350	2300 ± 250

Inch Taperlock Studs		
Thread Size	Standard Torque	
	N•m	lb ft
1/4	8 ± 3	6 ± 2
5/16	17 ± 5	13 ± 4
3/8	35 ± 5	26 ± 4
7/16	45 ± 10	33 ± 7
1/2	65 ± 10	48 ± 7
5/8	110 ± 20	80 ± 15
3/4	170 ± 30	125 ± 22
7/8	260 ± 40	190 ± 30
1	400 ± 60	300 ± 45
1 1/8	525 ± 60	390 ± 45
1 1/4	750 ± 80	550 ± 60
1 3/8	950 ± 125	700 ± 92
1 1/2	1200 ± 150	890 ± 110

Standard Torque for Metric Fasteners

Note: Take care to avoid mixing metric and inch dimensioned fasteners. Mismatched or incorrect fasteners can result in vehicle damage or malfunction, or possible injury.

Exceptions to these torques are given in the Service Manual where needed.

Note: Prior to installation of any hardware, be sure components are in near new condition. Bolt and threads must not be worn or damaged. Hardware must be free of rust and corrosion. Clean hardware with a non-corrosive cleaner and apply engine oil to threads and bearing face. If thread lock or other compounds are to be applied, do not apply engine oil.

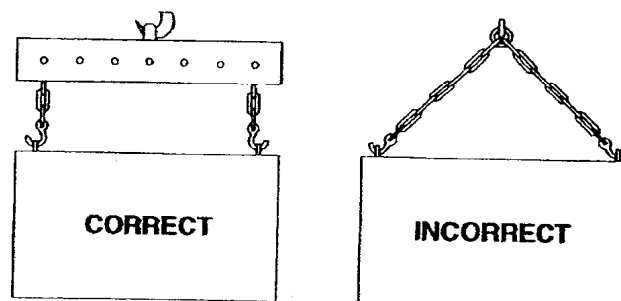
Standard Torque for Inch Fasteners

Exceptions to these torques are given in the Service Manual where needed.

When a bolt secures an internal part, or is on a rotating part, it could require a special torque. Whenever this situation arises, always check the engine's service manual or consult with Caterpillar Engineering for recommended tightening torque.

When adding brackets to an engine, be sure to use bolts of the correct length. Existing bolts could be too short and may not have enough threads to hold the part securely. A bolt which is too long may *bottom* before the seat is tight against the part. The threads in the assembly can also be damaged when a *long* bolt is used. It is not recommended to remove bolts from a gasketed joint for clipping or adding brackets.

Installation (or removal) of an engine should be accomplished by using a lifting beam or spreader bar. All supports (chains and cables) should be parallel to each other and as nearly perpendicular as possible to the top of the engine as shown in Figure 2.

**Figure 2**

Air Intake System

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GENERAL REQUIREMENTS

The function of the air intake system is to furnish an adequate supply of clean, dry, low temperature air to the engine. Failing this, increased maintenance costs and/or performance problems are certain to result. The following recommendations must be observed in order to obtain a satisfactory installation:

Every installation must include an efficient provision for removing dirt particles from the intake air.

The air inlet location and piping routing must be chosen to best obtain cool air. All joints should be air tight and all pipes properly supported. The air inlet must be designed to minimize the ingestion of water from rain storms, road splash, or the vehicle washing process.

The system maximum air restriction can effect engine emissions and must not be exceeded. For specific engine limits see the *Truck Engine Data Sheet*.

If breakaway pipe joints are used, they must be located upstream of the air cleaner.

AIR CLEANER

Dirt is the basic source of engine wear. Most dirt enters the engine via the inlet air. Cylinder walls or liners, pistons, piston rings, valves, valve guides and, in fact, any engine moving part is subjected to accelerated wear when undue amounts of dirt are contained in the inlet air. Therefore, careful air cleaner selection is vital to a good engine installation.

Dry-type air cleaners are recommended for Caterpillar Truck Engines.

The following information will be of help when designing an air cleaner system for Caterpillar Engines.

Service Life

The air cleaner must be sized so that initial restriction is low enough to give acceptable life within the maximum allowable restriction of the air inlet system.

Air Flow

Refer to the *Truck Engine Data Sheet*. The value given as combustion air flow is for full load Bhp at SAE conditions.

Restriction

Pressure drop across a typical air cleaner will be 6.0 in. H₂O when clean. The piping system might typically add another 3.0 in. H₂O pressure drop. For maximum permissible air restriction for a dirty air cleaner element refer to the *Truck Engine Data Sheet*. To provide for satisfactory engine performance and adequate filter element service life, the element should be sized as large as practical. The 9.0 in. H₂O initial pressure drop is an important measure of the expected element service life. Generally, the maximum initial (clean dry) restriction recommendation is 15 in. H₂O. See the *Truck Engine Data Sheet* for specific engine limits.

Service Indicator

Vacuum sensing devices designed to indicate the need for air cleaner servicing are commercially available and when added to the air intake system, serve a vital function. One of the following types is recommended for use:

- The trip lock device which indicates that the air cleaner condition is either satisfactory or when in need of service; it has a red display. The device is preset to indicate when filter service is needed.
- The latching type device that always latches at graduated levels of inlet restriction. The device measures restriction in inches of water vacuum and signals not only when engine is on but when the engine is shut down, so operator can check filter condition at any time.

- The third type is the direct reading gauge (usually in the cab) that indicates inches of water vacuum, when the engine is in operation.

One of the above service indicators should be connected in the air piping from the air cleaner to the turbocharger, near the turbocharger. If the indicator is mounted on the air cleaner, the setting should be adjusted to indicate need for service before the point of maximum system restriction is reached (since additional piping restriction is encountered downstream of the air cleaner).

Air Cleaner Efficiency

The air cleaner selection should be based upon the following efficiency considerations:

Performance Test

A satisfactory air cleaner must meet the requirements of the SAE Air Cleaner Test Code J726, Section 3. The *filter must have 99.5% efficiency minimum* as calculated by this test code with additions and exceptions as follows:

- Air flow corrected to ft³/min. at 29.61 in. Hg (100 kPa) pressure and 77°F (25°C).
- Use sonic dust feeder.
- Use Powder Technology Inc. (PTI) fine dust.
- Filter to be dried and weighed in an oven at 225±5°F (107±2°C) before and after test.

99.5% filtration of the PTI fine dust has been determined to be a practical combination of the kind of dirt likely encountered in over-the-road service at an air cleaner efficiency expected to give optimum engine wear life.

Dust Particle Size Effects

The above test procedure will have established sufficient control on the filter media particle size filtering ability of the tested air cleaner. Variables needing further control include:

- Choose filters supplied by manufacturers that can best provide quality control.
- Filters should be designed to be resistant to damage at initial assembly or during cleaning. End seal and filter media both are subject to damage which can result in dust leakage into the engine.
- Dirt can be built into the piping at initial assembly, enter the system during the filter change or be sucked into leaks in the piping system.

Two-Stage Air Cleaners

For conditions in which dust concentrations are higher or increased service life is desired, air cleaners are available with a precleaning stage. This precleaner imparts a swirl to the air, centrifuging out a major percentage of the dirt particles which may be collected in a reservoir or exhausted out on either a continuous or an intermittent basis.

Oil Bath Air Cleaner

Oil bath air cleaners, while sometimes required to meet customer specifications, are not recommended by Caterpillar. At best their efficiency is 95% as compared to 99.5% for dry-type filters. In addition to being less efficient, their relative ease of service and insensitivity to water advantages are easily outweighed by disadvantages, such as:

- Low ambient temperatures, low oil level, low air flow (such as when truck is at low idle) and truck tilt angle lessens efficiency further.
- Oil carry over, whether resulting from overfilling or increased air flow, can seriously affect turbocharger and engine life.

SYSTEM

The dry-type filter efficiency is not affected by angle of orientation on the vehicle. Special care should be taken, though, in arranging the filter housing and the piping, to insure that dirt retained in the filter housing is not inadvertently dumped into the engine air supply by service personnel during the air cleaner service operation. A vertically mounted air cleaner with bottom mounted engine supply pipe would be particularly vulnerable to this occurrence. For applications involving off-highway operation or extremely dusty conditions, a filter design incorporating a secondary or *safety* element which remains undisturbed during many change periods should be used. Its higher initial cost is offset by its contribution to longer engine life.

Intake

The air inlet should be shielded against direct entrance of rain or snow. The most common practice is to provide a cap or inlet hood which incorporates a coarse screen to keep out large objects. This cap should be designed to keep air flow restriction to a minimum. Some users have designed a front air intake which gives a direct air inlet and an internal means of achieving water separation.

Precleaners and prescreeners incorporated into the intake cap design are also available. They can be used where special conditions prevail or to increase the air cleaner service life. These devices can remove 70-80% of the dirt. The prescreener is designed to protect the inlet system when trash is encountered.

System Design

Routing

In addition to locating the inlet so that coolest possible air is used and engine exhaust gas is not ingested, it is best to locate the piping away from the vicinity of the exhaust piping when possible to do so. The maximum recommended air temperature rise is 20°F between ambient and the engine inlet (usually compressor inlet). (Example: 130°F maximum at 110°F ambient temperature).

Underhood air cleaners make this more difficult to achieve but higher temperatures can affect engine performance, as shown in Figure 3.

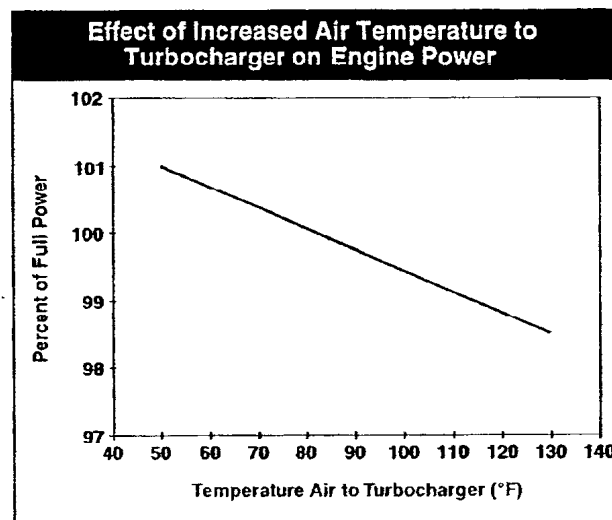


Figure 3

Higher air temperature can also affect turbocharger compressor wheel life, particularly at the high turbocharger speeds seen at altitude. The higher temperatures can give lower intake manifold pressures which results in increased fuel consumption and slower response to a load change.

Every 1° rise in temperature to the turbocharger passes through the turbocharger as a 1° rise in temperature to the charge air cooler. Only 80-88% of this rise is removed by the CAC, the remainder increases the intake manifold temperature. This rise makes the CAC sizing more difficult. (See Air-to-Air AfterCooling Systems.)

Diameter

Piping diameter should be equal to or larger than the air cleaner inlet and outlet and the engine air inlet. A rough guide for pipe size selection would be to keep maximum air velocity in the piping in the 2000-3000 fpm range.

Flexibility

To allow for minor misalignment due to manufacturing tolerances, engine to cab relative movement and to isolate vibrations, segments of the piping should consist of flexible rubber fittings. These are designed for use on diesel engine air intake systems and are commercially available. These fittings include hose connectors and reducers, rubber elbows and a variety of special shapes. Wire reinforced flexible hose should not be used. Most material available is susceptible to damage from abrasion and abuse and is very difficult to seal effectively at the clamping points unless special ends are provided on the hose.

Pipe Ends and Hose Connections

Beaded pipe ends at hose joints are recommended. Sealing surfaces should be round, smooth and free of burrs or sharp edges that could cut the hose. The tubing should have sufficient strength to withstand the hose clamping forces. Avoid the use of plastic tubing since it can lose much of its physical properties when subjected to engine compartment temperatures of up to 300°F. Either "T" bolt type or SAE type F hose clamps providing a 360° seal should be used. They should be top quality clamps.

Breakaway Joints

Breakaway joints may, if carefully designed, be used upstream of the air cleaner but never between the air cleaner and engine. When breakaway joints are required, choose a joint designed for lifetime sealing under the most severe conditions and needing little or no maintenance.

Piping Support

Bracing and supports are required for the piping. The turbocharger inlet piping must be supported when its weight exceeds 20 lb-ft (27 Nm). Unsupported weight on clamp-type joints should not exceed 3 lb (1.5 kg).

Straight Section Before Turbocharger

When possible, the piping to the turbocharger inlet should be designed to insure that air is flowing in a straight uniform direction into the turbocharger compressor. A straight section of at least 2 or 3 times pipe diameter is recommended.

Exhaust System

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GENERAL REQUIREMENTS

In order for an engine to produce its rated horsepower, attention should be given to exhaust gas flow restriction. Stringent legislation requirements on vehicle noise limits may require more restrictive exhaust systems.

- When checked by Caterpillar's recommended method, the exhaust backpressure must not exceed the limit given on the *Truck Engine Data Sheet*.
- The exhaust piping must allow for movement and thermal expansion so that undue stresses are not imposed on the turbocharger structure or exhaust manifold.
- *Never allow the turbocharger to support more than 20 lb-ft (27 Nm).*

MUFFLER SELECTION

The muffler or silencer is generally the single element making the largest contribution to exhaust backpressure. The factors that govern the selection of a silencer include: available space, cost, sound attenuation required, allowable backpressure, exhaust flow, and appearance.

Silencer design is a highly specialized art. The silencer manufacturer must be given responsibility for the details of construction. For exhaust gas flow and temperatures, see the *Truck Engine Data Sheet*.

Exhaust Backpressure

Backpressure has an effect on the response of an engine to load changes, exhaust temperatures, and fuel consumption. Exhaust systems should be designed for about 25 in. of water to provide the best compromise between noise and backpressure. Sometimes the vehicle requirements may cause the designer to exceed 25 in. of water. Caterpillar Engines are certified for smoke and gaseous emissions under Federal, California and other agency regulations with backpressure up to the values listed in the *Truck Engine Data Sheets*.

- Exhaust stack temperatures increase about 1.5°F for every 1 in. of water backpressure.
- The following examples show engine performance changes from a muffler rated at 25 in. of water at rated engine speed and load to one at 40 in. of water at rated speed and load:

Engine 1

- 2100 rpm 325 hp
1.3 hp decrease
0.4% fuel consumption increase
- 1500 rpm 330 hp
1.6 hp decrease
0.5% fuel consumption increase

Engine 2

- 2100 rpm 425 hp
5.0 hp decrease
1.2% fuel consumption increase
- 1500 rpm 390 hp
2.1 hp decrease
0.5% fuel consumption increase

Engine 3

- 1800 rpm 310 hp
3.6 hp decrease
1.1% fuel consumption increase
- 1500 rpm 295 hp
2.0 hp decrease
0.6% fuel consumption increase

Engine 4

- 2600 rpm 250 hp
1.0 hp decrease
0.4% fuel consumption increase
- 1500 rpm 185 hp
0.3 hp decrease
0.2% fuel consumption increase

As a general rule of thumb, muffler manufacturers indicate that fuel economy of the truck decreases an average of 0.5% per 13.5 in. of water increase in backpressure.

Exhaust Backpressure Calculations

Sharp bends in the exhaust system will increase exhaust backpressure significantly. The pipe adapter diameter at the turbocharger outlet is sized for an average installation. This size decision assumes a minimum of short radius bends. If a number of sharp bends are required, it may be necessary to increase the exhaust pipe diameter. Since restriction varies inversely with the fifth power of the pipe diameter, a small increase in pipe size can cause an appreciable reduction in exhaust pressure. Since silencer restriction is related to inlet gas velocity, in most cases a reduction in muffler restriction for a given degree of sound attenuation will require a larger silencer with larger pipe connections.

It is essential that the system does not impose more than the allowable maximum backpressure. The maximum backpressure can not be exceeded in certifying each engine model for conformity to exhaust smoke and exhaust gas emissions under Federal, California and other agency regulations. To avoid this problem, exhaust system backpressure should be calculated before finalizing the design.

Estimation of the piping backpressure can be done with this formula:

$$P = \frac{0.22LQ^2}{D^5 (460 + T)}$$

Where:

P = Pressure drop (backpressure)
measured in inches of water.

L = Total equivalent length of pipe in feet.

Q = Exhaust gas flow in cubic feet per
minute at rated conditions.

D = Inside diameter of pipe in inches.

T = Exhaust temperature in °F.

Values of D^5 for common pipe sizes are given above, top right:

Nominal Pipe Dia.	Actual ID	D^5
3.0	2.88	198.
3.5	3.38	441.
4.0	3.88	879.
5.0	4.88	2768.
6.0	5.88	7029.

To determine values of straight pipe equivalent length for smooth elbows use:

Standard 90° elbow =

33 x pipe diameter

Long sweep 90° elbow =

20 x pipe diameter

Standard 45° elbow =

15 x pipe diameter

To determine values of straight pipe equivalent length for flexible tubing use:

$$L = L_f \times 2$$

Exhaust backpressure is measured as the engine is operating under rated conditions. Either a water manometer or a gauge measuring inches of water can be used. If not equipped, install a pressure tap on a straight length of exhaust pipe. This tap should be located as close as possible to the turbocharger or exhaust manifold on a naturally aspirated engine, but at least 12 in. downstream of a bend. If an uninterrupted straight length of at least 18 in. is not available (12 in. preceding and 6 in. following the tap), take care to locate the probe as close as possible to the neutral axis of the exhaust gas flow. For example, a measurement taken on the outside of a 90° bend at the pipe surface will be higher than a similar measurement taken on the inside of the pipe bend. The pressure tap can be made by using a 1/8 NPT *half coupling* welded or brazed to the desired location on the exhaust pipe. After the coupling is attached, drill a .12 in. diameter hole through the exhaust pipe wall. If possible, remove burrs on the inside of the pipe so that the gas flow is not disturbed. The gauge or gauge hose can then be attached to the *half coupling*.

PIPING

When routing the exhaust system, consider each of the following factors:

Flexible Joints

Flexible joints are needed to isolate engine movement and vibration and to offset piping expansion and contraction. From its cold state, a steel pipe will expand .0076 in. per ft per 100°F temperature rise. For example, the expansion of 10 ft of pipe with a temperature rise of 50°F to 850°F is .61 in. If not accounted for, the piping movement can exert undue stress on the turbocharger structure and the pipe supports.

The maximum allowable load that the turbocharger is permitted to support is 20 lb-ft (27 Nm). This usually requires that a support be located within four feet of the turbocharger, with a flexible connection located between the turbocharger and the support. Manifolds for naturally aspirated engines can support up to 50 lb.

Flexible joints should be located in a longitudinal run of pipe rather than on a transverse section. This allows flexibility for engine side motion.

Water

Water must not be permitted to enter the engine through the exhaust piping.

A low horizontal exhaust pipe mounting is sometimes used, but it is difficult to find a place under the chassis where the exhaust gas can be discharged without adversely affecting some aspect of vehicle design. The tailpipe should be tipped to the side and inboard to avoid noise bounce off the road and excessive heat on the tires.

A vertical silencer mounting is more common. The exhaust outlet should be located so that fumes do not enter the air cleaner or the cab under any operating condition of the vehicle. Water protection for vertical systems can involve these items:

Rain Cap

Outlet Bend

A bend at the outlet is quite common. If it is the sole method of excluding moisture, the bend should be a full 90 degrees, and the exhaust outlet directed towards the rear of

the vehicle. However, local laws should be considered since silencing effectiveness may be altered.

Drain Holes

Drain holes near a low point in the piping are used. Holes smaller than 1/8 in. have a tendency to become plugged, and unfortunately holes of that size or larger are likely to be a source of noise and focus for corrosion.

Consider installing a small drained expansion chamber in the piping.

CONVERTER/MUFFLERS

Although a catalytic converter has been required on some in engines in past years, a catalytic converter is not required on any truck engines for certification in 1998.

AUXILIARY EXHAUST BRAKES

Caterpillar concurs with the use of auxiliary exhaust braking devices on the 3406, 3116, 3126, 3126B and 3208 T Engines, with limits as outlined in *Section IVII Auxiliary Braking Devices*.

EXHAUST PYROMETERS

While not offered by Caterpillar, an exhaust pipe thermocouple and related instrument panel mounted pyrometer is sometimes installed by the truck owner. Take care in mounting the thermocouple to not increase the exhaust backpressure.